OPERATION AND SERVICE MANUAL

FOR

GMC TYPE 451-1

MICROWAVE POWER METER

EE DEPT.

GENERAL MICROWAVE
CORPORATION

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MICROWAVE POWER METER

SERIAL NUMBERS 101 AND HIGHER

GENERAL MICROWAVE CORPORATION

FARMINGDALE, NEW YORK

TABLE OF CONTENTS

		Page
1.	GENERAL	
	1.1 DESCRIPTION OF INSTRUMENT	1
	1.2 ELECTRICAL AND MECHANICAL SPECIFICATIONS	1-2
	1.3 230 VOLT OPERATION	2
2.	OPERATING INSTRUCTIONS	
	2.1 OPERATING CONTROLS AND PROCEDURE	4-5
	2.2 INSTRUMENT BEHAVIOUR WITHOUT EXTERNAL BOLOMETER	5
	2.3 CAUTIONARY NOTE ON BOLOMETER CONNECTION	5
	2.4 BOLOMETER CHARACTERISTICS	5-7
	2.5 MEASUREMENT OF MODULATED POWER	7-8
3.	THEORY OF OPERATION	
	3.1 GENERAL CIRCUIT DESCRIPTION	9
	3.2 BOLOMETER BRIDGE	10
	3.3 BRIDGE OSCILLATOR	10-11
	3.4 POWER SUPPLY	11
4.	MAINTENANCE AND CALIBRATION PROCEDURE	
	4.1 GENERAL DISCUSSION	12
	4.2 TEST EQUIPMENT REQUIRED FOR CALIBRATION AND SERVICE	12
	4.3 SIMPLIFIED PERFORMANCE CHECK	12
	4.4 POWER SUPPLY ADJUSTMENT AND PERFORMANCE CHECK	13
	4.5 MEASUREMENT OF DC BIAS CURRENT	13
	4.6 VOLTMETER CALIBRATION	13-14
	4.7 VOLTMETER STABILITY	14
	4.8 BOLOMETER BRIDGE RESISTANCE RATIO	14-15
5.	TABLE OF REPLACEABLE PARTS	19, 20, 21, 22, 23, 24, 25

SECTION 1 - GENERAL

1.1 DESCRIPTION OF INSTRUMENT

The GMC Type 451-1 Microwave Power Meter is a self-balancing audio substitution bridge capable of measuring power from a few microwatts to 10 milliwatts when used with appropriate bolometers. The frequency range of the signal to be measured is a function of the particular mount in use.

The bridge can be used with either positive coefficient detectors such as barretters, fuses and Wollaston wires or with negative coefficient detectors such as thermistors whose resistance can be brought to 100 or 200 ohms with 0 to 16 ma of d-c bias plus audio power up to about 12 milliwatts.

The r-f power absorbed by the bolometer is read directly on the meter in both milliwatts and dbm. Power in excess of 10 milliwatts can be measured by use of appropriate pads.

1.2 ELECTRICAL AND MECHANICAL SPECIFICATIONS

1.2.1 POWER RANGE: Five ranges with full scale readings of 0.1, 0.3, 1.0, 3.0 and 10 mw. Corresponding dbm scales are -10, -5, +5 and +10 dbm.

1.2.2 FREQUENCY RANGE: Dependent only on external bolometer and mount used.

1.2.3 EXTERNAL BOLOMETERS: Either positive or negative coefficient can be used at either 100 or 200 ohms. Some typical bolometers are:

Barretters: Sperry 821, Narda 821B or N610B, PRD 610A, 614, 617, or 631C.

Thermistors: W.E. D166382 or 32A3, VECO. 32A3 or 32A5, Narda 333 or 334, PRD 631G.

Fuses: HP G-28A 0.01 amp. fuse

1.2.4 BIAS CURRENT: D-C bias current variable from 0 to 16 ma.

1.2.5 ACCURACY: ±5% of full scale reading.

1.2.6 INPUT POWER: 115/230V ±10%, 50 to 1000 cps, approximately 90 watts (see 1.3 below).

1.2.7 DIMENSIONS:

Cabinet Mount: 7-1/2" w x 11-1/2" h x 14" d

Rack Mount: 19" w x 7" h x 14-1/4" d

1.2.8 WEIGHT:

Cabinet Mount: 14 lbs.

Rack Mount: 17 lbs.

1.3 230 VOLT OPERATION

The GMC Type 451-1 is normally shipped with connections for 115 volt operation. To convert to 230 volt operation:

a. Remove the bare jumpers between terminals 1-8 and 2-9 on the transformer.

b. Install a jumper between terminals 2-8.

c. Replace fuse with a 0.5 amp size.

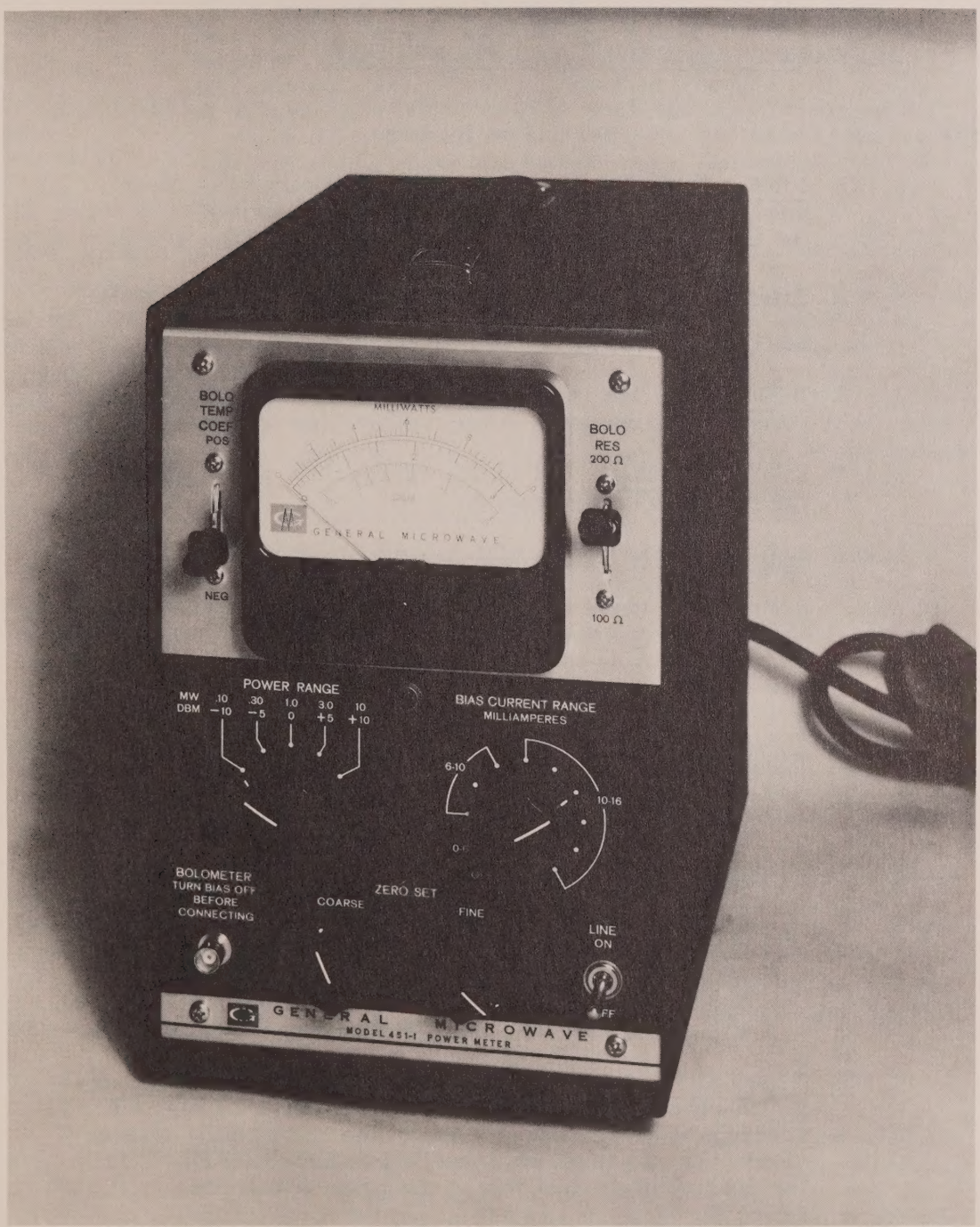

FIGURE 1. FRONT PANEL VIEW OF GMC TYPE 451-1 MICROWAVE POWER METER

SECTION 2 - OPERATING INSTRUCTIONS

2.1 OPERATING CONTROLS AND PROCEDURE

The operating controls of the instrument are shown in Fig. 1. The general operating procedure is as follows:

2.1.1 LINE: Turn ON to apply power to all circuits. Bias power is not applied as long as the bias switch is in the OFF position.

2.1.2 BOLO TEMP COEF: Set in accordance with the coefficient of the bolometer to be used, either POSITIVE or NEGATIVE.

2.1.3 BOLO RES: Set in accordance with the resistance of the bolometer to be used, either 100 or 200 OHMS.

2.1.4 POWER RANGE: Select the appropriate power range for the power to be measured.

2.1.5 BOLOMETER: Turn BOLO BIAS CURRENT switch to OFF. Rotate ZERO SET controls fully counter-clockwise. Connect bolometer to BNC jack with suitable shielded cable. Failure to follow this procedure before connecting or disconnecting the bolometer may result in bolometer damage.

2.1.6 BOLO BIAS CURRENT: Rotate clockwise until position is reached which will allow ZERO SET controls to bring meter to zero. Use the lowest setting possible. Excess current may damage the bolometer.

> WARNING: THE SWITCHING TRANSIENT THAT RESULTS WHEN THE BIAS CURRENT SWITCH IS TURNED FROM OFF TO THE FIRST POSITION OR FROM THE FIRST POSITION TO OFF, MAY DAMAGE LOW CURRENT BOLOMETERS UNLESS THE ZERO SET CONTROLS ARE FIRST ROTATED FULLY COUNTER-CLOCKWISE.

2.1.7 ZERO SET: Adjust slowly clockwise to bring meter reading to zero. If unable to reach zero, with ZERO SET controls fully clockwise, return the controls to counter-clockwise position, advance BOLO BIAS CURRENT to the next position and repeat the procedure.

Apply r-f power to the bolometer and take reading.

2.1.8 INSTRUMENT AND MOUNT STABILIZATION: A limitation to the accuracy obtainable from the GMC Type 451-1 **Microwave Power Meter is the stability of both the instrument** and the external bolometer. For power measurements on the upper ranges, a warm-up period of 10 to 15

minutes is usually quite adequate to stabilize the instrument, while on the lowest range, a one hour warm-up is recommended to realize the full potential of the Power Meter performance. As for the mount, it should be remembered that it is a temperature sensitive device, and inconsistent results will be obtained where a cold mount is secured to a warm object. One should allow the mount to reach thermal equilibrium with the equipment under test and should make the power measurement as soon as possible after zeroing the meter.

2.2 INSTRUMENT BEHAVIOUR WITHOUT EXTERNAL BOLOMETER

The front panel meter of the instrument will generally behave erratically when the unit is turned on without an externally connected bolometer. For example, with the BOLO TEMP COEF switch in the POSITIVE position, the needle will pin up scale. With the switch in the NEGATIVE position, the needle will read down scale or oscillate against the down-scale pin. This behaviour is normal for the instrument under these circumstances and will stop as soon as the bolometer is connected.

2.3 CAUTIONARY NOTE ON BOLOMETER CONNECTION

As indicated above, it is essential that the BOLO BIAS CURRENT switch be in the OFF position before either connecting or disconnecting the bolometer to avoid damage to the bolometer. This is especially true in the case of platinum wire barretters which have a very low safe overload factor.

In the case of low power barreters, such as the PRD 610A and 631C, nominal operating bias is rated at 4.5 ma. This current is available in the first position of the BOLO BIAS CURRENT switch and extreme care should be exercised to avoid exceeding this current when using bolometers of this type.

Higher power barretters, such as the Sperry 821B, are nominally biased at 8.75 ma, available in the second through fourth positions of the BOLO BIAS CURRENT switch. The higher current positions of the switch are normally used with thermistor elements such as the PRD 631G or H-P 477B. In all cases, the BOLO BIAS CURRENT should be turned up only after it has been determined with complete certainty that the meter cannot be zeroed on a lower current setting.

2.4 BOLOMETER CHARACTERISTICS:

2.4.1 GENERAL: The GMC Type 451-1 Microwave Power Meter is designed to operate with a wide variety of bolometer elements with both positive and negative temperature coefficients. All these devices possess the ability to absorb r-f power and change resistance due to their consequent increase in temperature. Table I lists the characteristics of some of the more commonly available bolometers that can be used with the GMC Type 451-1.

TABLE 1 NOMINAL CHARACTERISTICS OF COMMONLY AVAILABLE BOLOMETERS

Make & Model	Temp. Coeff.	Max. Pwr. MW	Max. Current MA	Cold Res. Ohms	Oper. Res. Ohms	Oper. Pwr. MW	Oper. Current MA	Sens. Ohms per MW	Time Const. Micro-sec.	3 db Freq. cps	Remarks
Narda N610B-100	Pos				100	7.7	8.75				Like 1N23
Sperry 821	Pos	32	10.5	110	200	15.3	8.75	4.5	350	450	(
Narda N821B	Pos	32	10.5	110	200	15.3	8.75	4.5	350	450	Fully interchangeable (
Narda N610B	Pos	32	10.5	110	200	15.3	8.75	4.5	350	450	Like 1N23
PRD 610A	Pos	7.5	6	160	200	4	4.5	10	100	1600	Like 1N23
PRD 614	Pos	7.5	6	160	200	4	4.5	10	100	1600	Like 1N26 crystal
PRD 617	Pos	7.5	6	160	200	4	4.5	10	100	1600	Wire element on mica sheet
PRD 631C	Pos			160	200	4	4.5	10			Two 100 ohm wires on mica
Buss MJB 1/100	Pos	60	14	140	200	15.3	8.75	3			Large variations
W. E. Co. D166382 D170575											D166382, 32A3 in glass bead, interchangeable
Victory 32A3 32A5	Neg	100	130	2000	100 200	14 9	12 6.7	13 36	106		D170575, 32A5 uncapsuled, interchangeable

2.4.2 BARRETTERS: Barretters are usually constructed of very fine platinum wires or thin metal films displaying positive temperature coefficients. They have relatively short time constants, as compared to thermistors, and are consequently able to follow low frequency modulation envelopes. This characteristic combined with their excellent square law behaviour, makes them useful as detectors for attenuation measuring systems but limits their usefulness as bolometers. (See Paragraph 2.5.1). The sensitivity of most barretters falls within the range of 4 to 10 ohms per milliwatt.

2.4.3 THERMISTORS: Thermistors, which display a negative temperature coefficient, are constructed of a small amount of a semi-conducting material suspended by two fine wires. This assembly may be found with and without glass encapsulation.

Compared to barretters, thermistors have a relatively long time constant and significantly higher sensitivity. They are capable of much greater safe overload and in general are more rugged in nature.

2.5 MEASUREMENT OF MODULATED POWER

Although under most conditions of maximum power measurement, the GMC Type 451-1 Microwave Power Meter will yield accurate readings, there are certain circumstances, when the input signal has a relatively low frequency modulation, when errors can occur. In addition, errors can arise at certain repetition rates of pulse modulated signals. These are described below in more detail.

2.5.1 LOW FREQUENCY MODULATION ERRORS: As indicated above in the discussion of barretters, the relatively short time constant of these bolometers permits them to follow the modulation envelope. In turn the bridge, attempting to maintain a balanced condition, will adjust its oscillatory level in step with the changing resistance of the bolometer. The result is an oscillator output with a low frequency modulation impressed upon it. The voltmeter, which is an average responding type, will now indicate the average power between the peak and valley of the modulation envelope. However, for accurate readings, the meter should respond to the rms voltage and thus an error will result. Since the average value of the waveform is lower than the rms value, the meter reading will be high. The actual error that results will depend upon the modulation frequency, the time constant of the bolometer and the transient behaviour of the bridge oscillator circuit. The use of a relatively high Q oscillator circuit in the Type 451-1 tends to lower the minimum permissible modulation frequency which can be measured without error. When the modulation frequency is of the order of 200 cps or below, the resultant error when using a barretter is of the order of 1 db. With a thermistor, modulation frequencies as low as 100 cps can be measured.

2.5.2 ERRORS IN MEASUREMENT OF PULSE MODULATION SIGNALS: In addition to the errors produced by modulation tracking, there is one other important contribution to power measurement error when dealing with pulse modulated signals. This error arises when the pulse repetition rate is a sub-multiple of the oscillator frequency. When small differences in the two frequencies exist, an actual beating will occur and is evidenced by rapid fluctuations of the meter reading. In some circumstances, the oscillator frequency will be pulled and will lock in on the pulse repetition rate. The effect is not nearly as pronounced and leads to negligible error when longer time constant thermistors are employed for power measurement.

SECTION 3 - THEORY OF OPERATION

3.1 GENERAL CIRCUIT DESCRIPTION

The major subassemblies of the GMC Type 451-1 Power Meter comprise a power supply and d-c bias network, audio oscillator, voltmeter circuit, and bolometer bridge as shown in Figure 2. Three arms of the bolometer bridge circuit are provided by the instrument and the bolometer or thermistor element forms the fourth arm.

When the bolometer is connected to the unbalanced bridge circuit, its resistance changes as it absorbs power from the audio frequency oscillator and d-c bias network. It continues to absorb power until its resistance is such as to balance the bridge. (This value is preselected by the operator). At balance, the oscillator power stabilizes. The voltmeter is zero set, and the instrument is ready for RF power measurement.

If the d-c bias power is changed, the audio frequency power will change to restore the bridge to balance. Similarly, when RF power is applied to the bolometer element and the bridge becomes unbalanced, the audio frequency power automatically decreases by an amount equal to the applied RF Power to rebalance the bridge. The voltmeter circuit measures this decrease in audio power but displays it on the indicating meter as an increase in RF Power.

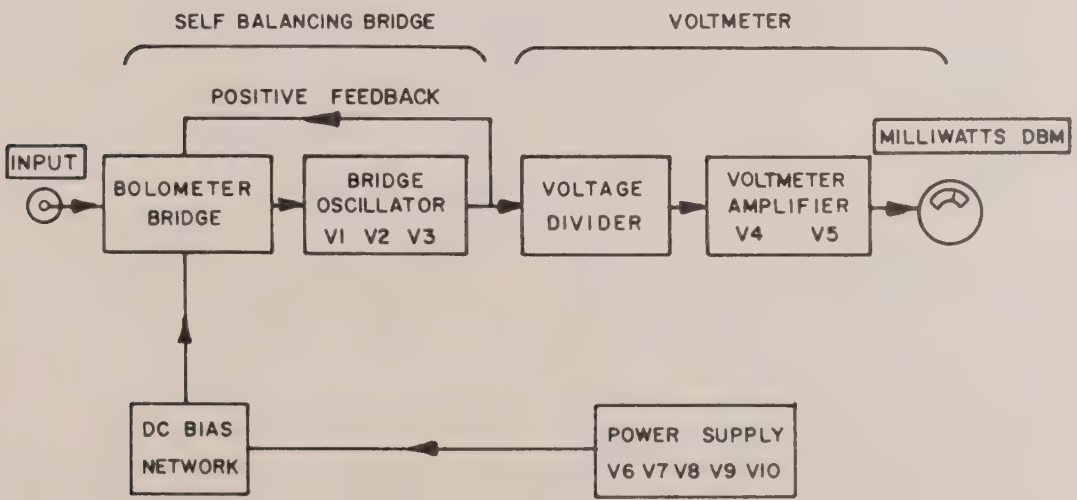

FIGURE 2 BLOCK DIAGRAM OF THE GMC TYPE 451-1

3.2 BOLOMETER BRIDGE

Figures 3 and 4 illustrate schematically the circuit arrangement of the bolometer bridge using 200-ohm positive and negative temperature coefficient detecting elements. To permit operation of the power meter with both 100- and 200-ohm bolometer elements, one leg of the bridge is made adjustable to either 200 or 400 ohms. In both cases, at balance, a 3-to-1 voltage ratio is established. The circled values represent the balance-voltage relationships while the numbers in squares represent resistance ratios. If the bridge is unbalanced, it will produce a change in the oscillator output (either an increase or decrease) in a direction tending to rebalance the bridge by changing the current through the bolometer element. The balancing resistance is that value pre-selected by the operator.

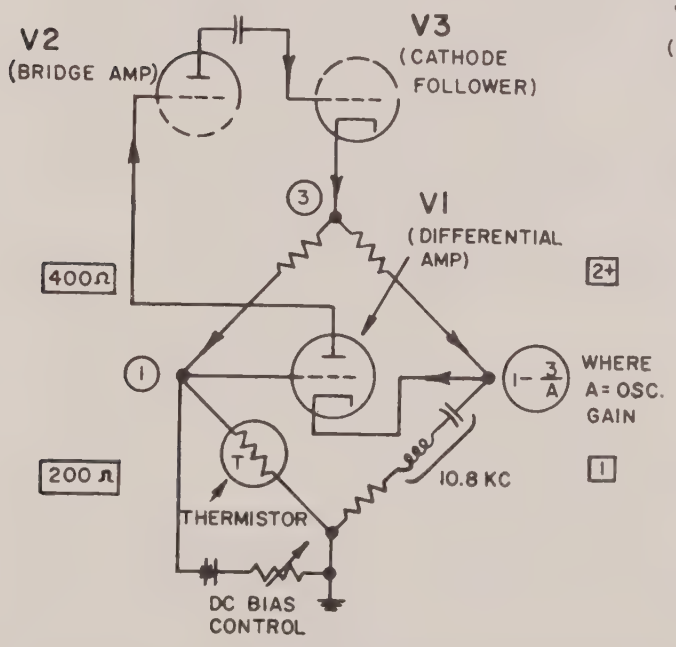

FIGURE 3
SIMPLIFIED SCHEMATIC SHOWING THE BRIDGE WITH A 200Ω THERMISTOR

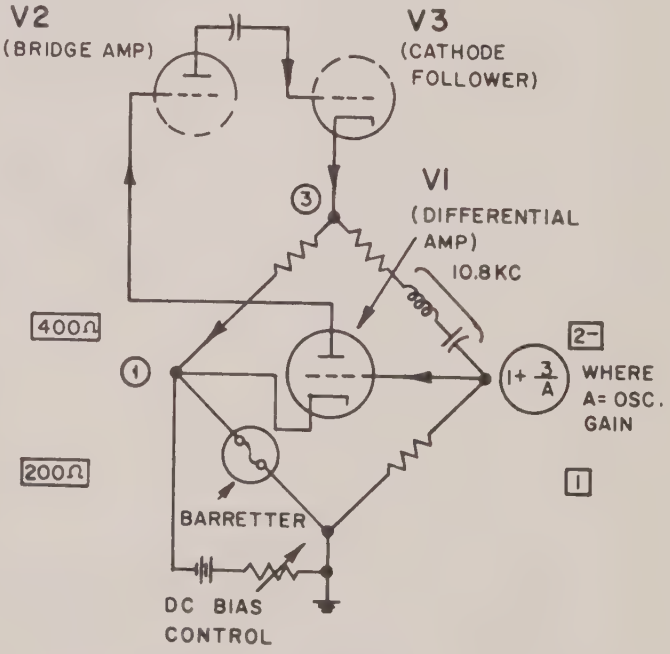

FIGURE 4
SIMPLIFIED SCHEMATIC SHOWING THE BRIDGE WITH A 200Ω BARRETTER

3.3 BRIDGE OSCILLATOR

The action of the bridge oscillator (V_1, V_2, and V_3 of Figures 3 and 4) is best illustrated by example. Assume the use of a 200-ohm barretter for the measurement of RF Power in the 0-1 milliwatt range, and that 4.0 milliwatts in the barreter element are required to drive it to 200 ohms. When the mount (with no RF applied) is initially connected to the power meter the resulting bridge unbalance causes the oscillator output to increase in an effort to effect a balance. The bridge is designed, however, to reach zero on the 1 mw scale when the oscillator output is only 1.2 milliwatts. To force the oscillator to deliver this smaller power and yet still dissipate the required 4 milliwatts in the barreter, 2.8 mw of d-c

bias are required. If this adjustment is made using the Bias Control and Zero Set Controls on the front panel, then the conditions of balance are met, i.e., the barreter power is 4 mw and the barreter resistance is 200 ohms. Upon the application of say 0.5 mw of RF power, the oscillator output decreases by an equal amount (in order to rebalance the bridge) leaving 0.7 mw of audio power, and the panel meter, which senses the change in oscillator output, displays a reading of 0.5 mw. The d-c bias remains constant throughout. The conditions of balance are again met, i.e., the total barreter power is 4.0 mw (2.8 mw of d-c bias plus 0.7 mw of audio power plus 0.5 mw RF Power) and the barreter resistance is 200 ohms.

With the exception that the bridge circuitry is rearranged as illustrated in Figure 3, the action for negative temperature coefficient detectors is the same.

3.4 POWER SUPPLY

The power supply of the GMC Type 451-1 Power Meter consists of a full-wave rectifier and a regulator section. The regulator section, shown in simplified form in Figure 5, employs a two-stage differential amplifier (V_8 and V_9), a voltage reference tube (V_{10}) and a series control tube (V_7). Differential amplifiers are employed since they are relatively insensitive to in-phase signals applied to the two grids. Thus the effects of heater voltage variation, tube aging, etc., are virtually eliminated.

The action of the regulator can be seen as follows. Assume that the B+ voltage tends to increase. This could occur as a result of an increase in line voltage or a reduction in load current. This increase in voltage is applied through R_{75} to the grid of V_{9B}. The grid of V_{9A} is held at a constant voltage, due to the voltage regulator tube, and so the plate of V_{9B} will drop, the voltage across R_{73} will rise since it follows the grid, and the plate of V_{9A} will rise. Since the grids of V_8 are directly coupled to the plates of V_9, the plate of V_{8B} will rise and that of V_{8A} will drop.

The effect of this action is a decrease in grid-to-cathode voltage of the series control tube, V_7. This produces an increase in beam resistance of that tube and, therefore, a greater voltage drop tending to reduce the B+ voltage. In the case of a decrease in B+, the regulator behaves exactly the same, but with reverse polarity. Similarly, hum voltage in the output is reduced by this action.

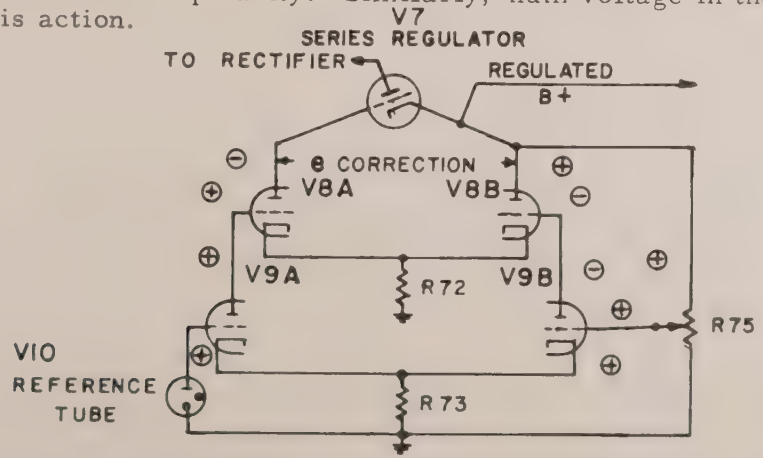

FIGURE 5 SIMPLIFIED SCHEMATIC OF THE VOLTAGE REGULATOR SECTION OF THE POWER SUPPLY

SECTION 4 - MAINTENANCE AND CALIBRATION PROCEDURE

4.1 GENERAL DISCUSSION

In general, when unable to zero set the bridge with the bolometer connected and with bias controls in their normal positions, it is best to first determine that the bolometer is not damaged. Substitution of another bolometer is advisable before proceeding to service the Power Meter itself.

4.2 TEST EQUIPMENT REQUIRED FOR CALIBRATION AND SERVICE

In order to maintain and service the power meter, any conventional high impedance vacuum tube voltmeter, tube checker and oscilloscope is all that is required. However, when attempting to calibrate the instrument, it is essential that a highly accurate a-c vacuum tube voltmeter be available in addition. Since the overall accuracy of the instrument is dependent upon a-c voltage calibration, the more accurate the reference standard, the more accurate performance one can expect of the Power Meter. It is recommended that a voltmeter accuracy of at least 0.25% be used. In addition to this, an adjustable line transformer and line voltmeter, as well as suitable bolometers, should be available.

4.3 SIMPLIFIED PERFORMANCE CHECK

It is possible to calibrate the power meter in a simplified fashion without removing it from its cabinet. The procedure for this test is as follows:

1. Connect a suitable 200 ohm bolometer to the input connector in parallel with an accurate a-c vacuum tube voltmeter. Keep in mind that the a-c voltage present at the front panel is approximately 10.8 kc. Using the BOLO BIAS CURRENT and ZERO SET controls, adjust the meter readings to zero on the 10 milliwatt range and measure the voltage across the bolometer.

2. Using the BOLO BIAS CURRENT and ZERO SET controls, readjust the meter reading to full scale and measure the voltage across the bolometer.

3. Repeat Steps 1 and 2 for the 1 milliwatt and 0.1 milliwatt ranges.

4. The measured voltages should fall within the ranges indicated below.

- 10 MW RANGE -		- 1 MW RANGE -		- 0.1 MW RANGE -	
VOLTAGE AT ZERO	FULL SCALE VOLTAGE LIMITS	VOLTAGE AT ZERO	FULL SCALE VOLTAGE LIMITS	VOLTAGE AT ZERO	FULL SCALE VOLTAGE LIMITS
1.50	0.387 - 0.592	0.474	0.122 - 0.187	0.150	0.0387 - 0.0592
1.52	0.459 - 0.641	0.481	0.145 - 0.203	0.152	0.0459 - 0.0641
1.54	0.521 - 0.687	0.487	0.165 - 0.217	0.154	0.0521 - 0.0687
1.55	0.550 - 0.709	0.490	0.174 - 0.224	0.155	0.0550 - 0.0709
1.56	0.578 - 0.730	0.493	0.183 - 0.231	0.156	0.0578 - 0.0730
1.58	0.630 - 0.772	0.500	0.199 - 0.244	0.158	0.0630 - 0.0772
1.60	0.678 - 0.813	0.506	0.214 - 0.257	0.160	0.0678 - 0.0813

4.4 POWER SUPPLY ADJUSTMENT AND PERFORMANCE CHECK

To adjust the regulated power supply and check its performance, the following procedure should be used:

1. With the instrument connected to the adjustable line transformer, set to deliver 117 volts, allow a warm up period of about one-half hour. The TEMP COEF switch should be in the POSITIVE position. There is no need for an external bolometer connection.

2. With a d-c vacuum tube voltmeter connected across C19c the ADJ PLUS 250v control (R75), should be set to give a reading of 250 volts.

3. The adjustable transformer should be varied from 103 to 127 volts. The permissible variation in power supply voltage should be not greater than ± 1%. A differential type voltmeter such as the Fluke Model 801 is most convenient for making a measurement of this type. At least 1 minute stabilization should be allowed before making each successive measurement.

4. Ripple voltage should be measured with an a-c vacuum tube voltmeter connected across C19c. The permissible level of ripple is 1 millivolt or less with the line voltage set anywhere between 103 and 127 volts.

4.5 MEASUREMENT OF DC BIAS CURRENT

The BOLO BIAS CURRENT steps and ZERO SET controls are designed to give overlapping ranges of d-c bias current to both 100 and 200 ohm bolometers. To check this performance, the following procedure can be used:

1. Connect an accurate 200 ohm resistor to the input connector in parallel with a d-c vacuum tube voltmeter. The TEMP COEF switch should be in the POSITIVE position and the BOLO RES switch in the 200 OHM position.

2. Remove V1 from its socket to disable the bridge oscillator.

3. With the BOLO BIAS CURRENT switch successively turned to each position, measure the d-c voltage at the input connection with the ZERO SET controls first in the fully counter-clockwise position and then in the fully clockwise position. There should be overlap on every range. The maximum voltage available should be at least 3.2 volts.

4.6 VOLTMETER CALIBRATION

To calibrate the voltmeter, connect the accurate a-c vacuum tube voltmeter between the CAL jack on the chassis and ground, and proceed in the following manner.

1. Set the instrument on the 1 mw scale. Set the BOLO TEMP COEF switch to POS and the BOLO RES switch to 200 OHMS.

2. Connect a 200-ohm barreter to the input and turn on the instrument. Bias power should be off before connecting the barreter.

3. Adjust the BOLO BIAS CURRENT switch and ZERO SET controls so that the external a-c VTVM reads 0.465 volts.

4. Set the ZERO ADJ. control (R_{58}) for zero reading on the meter.

5. Adjust the ZERO SET controls to obtain a reading of 0.190 volts on the external a-c VTVM.

6. Set the F. S ADJ. control (R_{63}) to obtain a full-scale reading on the meter

7. Repeat steps 3 through 6 until no improvement can be made.

4.7 VOLTMETER STABILITY

To determine whether the instrument vacuum tube voltmeter has the required stability, the following procedure should be followed:

1. Connect an a-c vacuum tube voltmeter between the chassis test point and ground.

2. Adjust the line voltage to 103 volts and connect a bolometer to the input connector. With the POWER RANGE switch set to the 1 milliwatt position, adjust the BOLO BIAS CURRENT and ZERO SET controls so that the external a-c vacuum tube voltmeter reads 0.3 volts. Note the meter reading of the GMC Type 451.

3. Increase the line voltage to 127 volts and readjust the ZERO SET controls so that the external a-c vacuum tube voltmeter again reads 0.3 volts.

4. Note the meter reading on the GMC Type 451-1. This reading should be within 2% of full scale of the reading taken under Step 3. Failure to meet this tolerance is usually a result of insufficient gain in tubes V4 and V5.

4.8 BOLOMETER BRIDGE RESISTANCE RATIO

This is a further check on the calibration accuracy of the instrument

and is included although it is doubtful that any adjustment will be necessary.

The bridge resistance adjustment (R8) establishes bridge balancing resistance for three conditions.

1. Thermistor, 200 ohms, negative coefficient.

2. Thermistor, 100 ohms, negative coefficient.

3. Fuse or Barretter, 200 ohms, positive coefficient.

The a-c VTVM used for this procedure must have a minimum accuracy of ±1/2% at 10 kc.

a. Set the BIAS CURRENT to OFF, the RESistance switch to 200 OHMS, and the COEFficient switch to NEGative. Connect a 200 ohm thermistor to the BOLOMETER jack.

b. Set the POWER RANGE to 1 MW and measure the a-c voltage between chassis and the junction of R2 and S2c.

This point is shown as the 3 volt test point on the schematic. Set the BIAS CURRENT and ZERO SET controls to obtain a voltage of 3.00 volts at this point.

c. Shift the a-c VTVM to the input connector.

This point is the 1 volt test point indicated on the schematic. The a-c VTVM should indicate between 1.01 and 0.99 volts, if it does no further check is necessary. If the voltage does not fall within these limits continue.

d. Adjust the BIAS CURRENT and ZERO SET controls to obtain an indication of 3.00 volts at the 3 volt test point located in steb b.

e. Shift the voltmeter to the 1 volt test point and note the error from 1.00 volts. Adjust R8 to double the error, for example if the voltmeter indication is .96, adjust R8 for an indication of .92.

f. Adjust the ZERO SET controls for an indication of 1.00 volts at the 1 volt test point.

g. Shift the voltmeter back to the 3 volt test point and note the voltage. If it is not 3.00 volts adjust the ZERO SET controls for 3.00 volts and repeat steps e, f, and g until no error is evident in these two voltages.

h. Repeat this procedure starting with step a. but substitute in turn a 100 ohm thermistor or a 200 ohm barretter until all three possibilities are checked. If an error in excess of 1% exists with any of these bolometers connected to the input, compromise the setting of R8 to divide the error equally between the three.

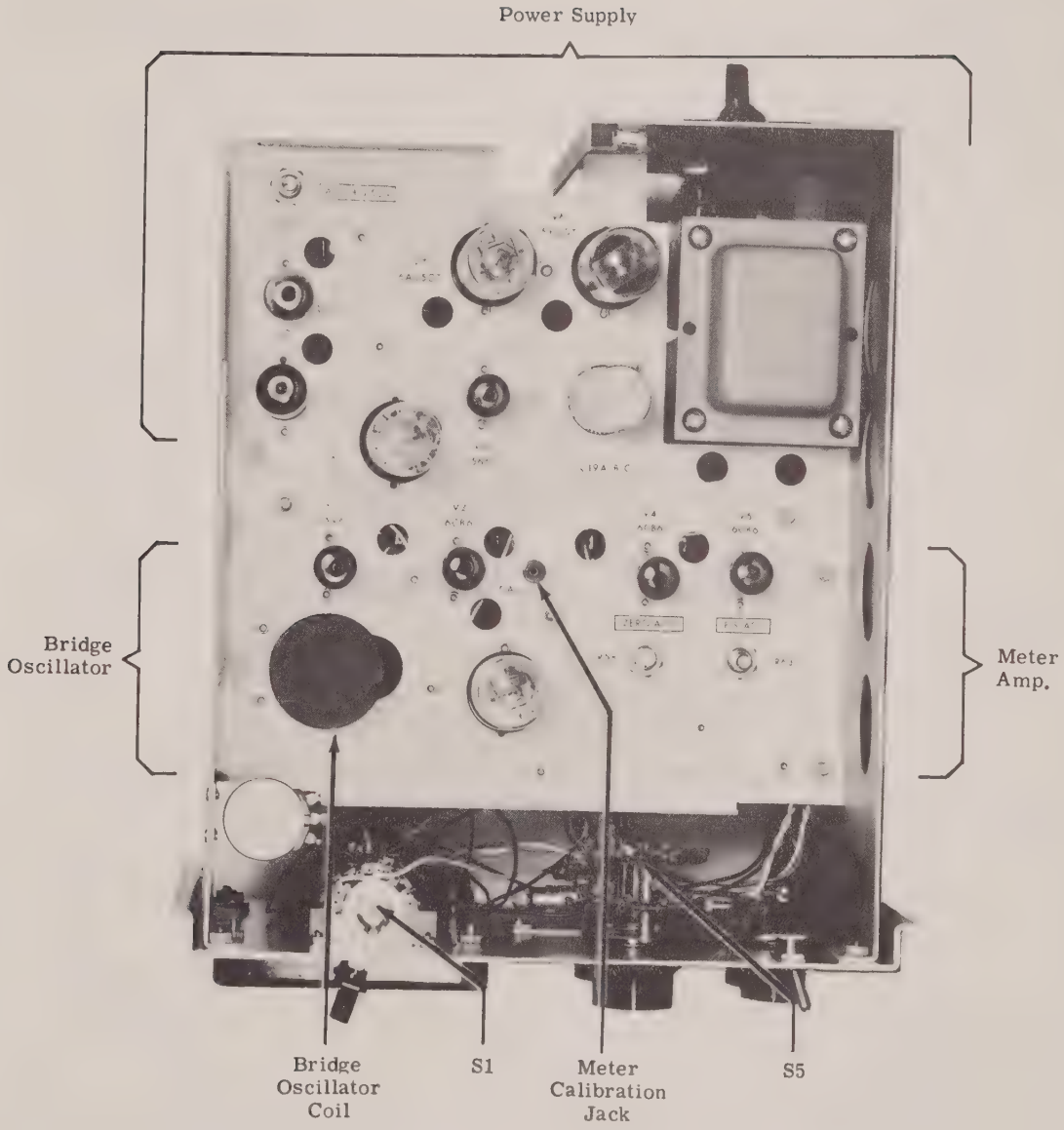

FIGURE 6 RIGHT SIDE VIEW WITH COVER REMOVED

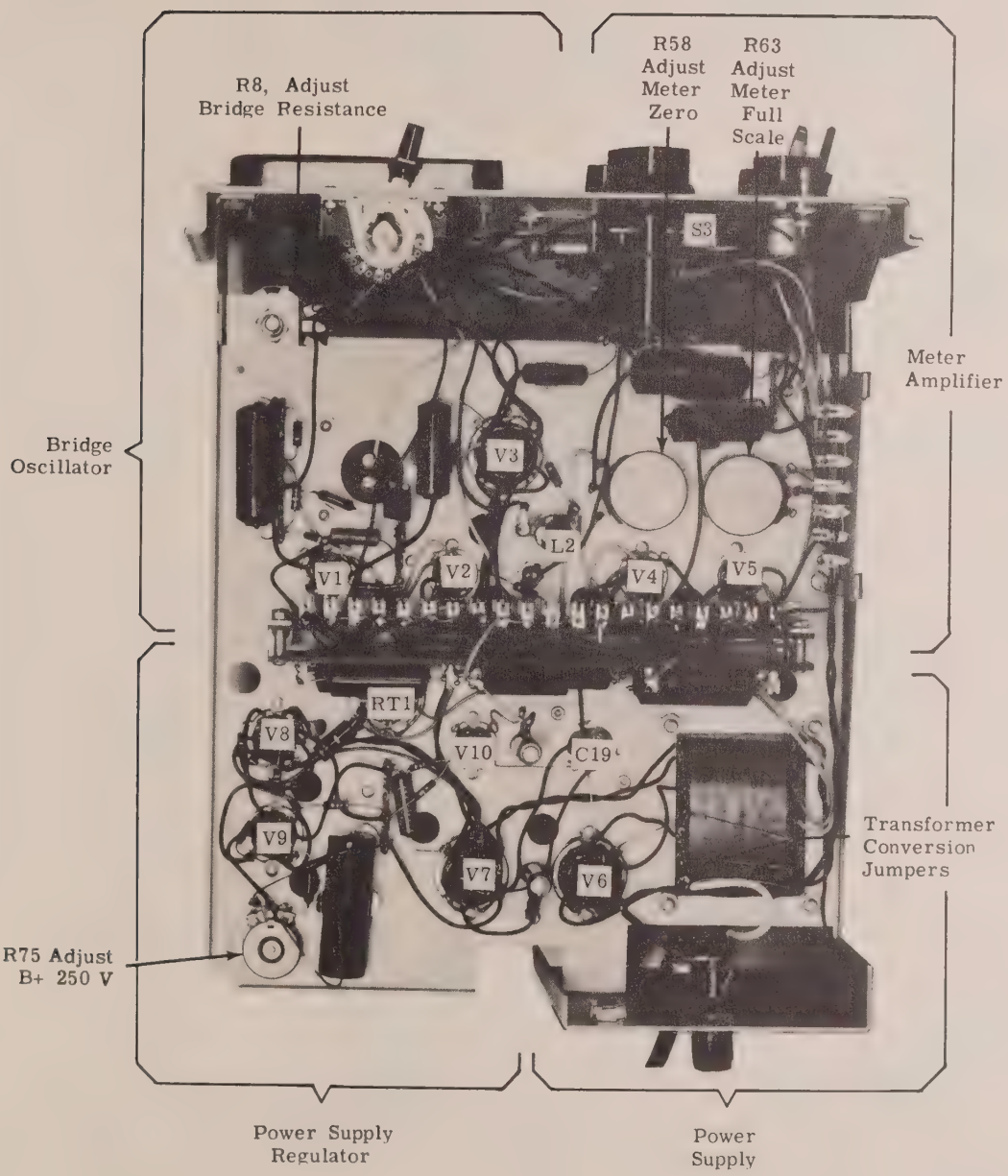

FIGURE 7 LEFT SIDE VIEW WITH COVER REMOVED

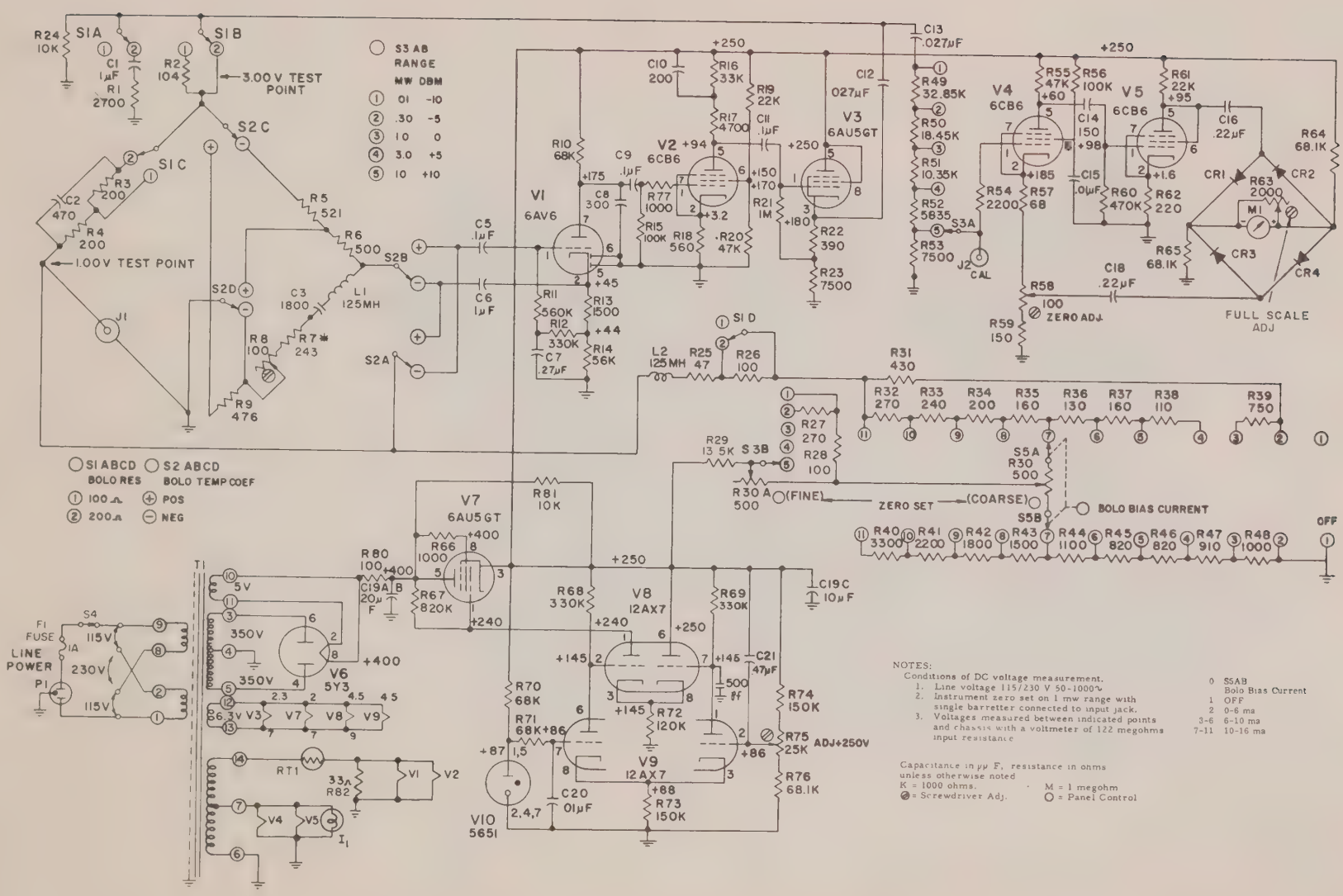

FIGURE 8 SCHEMATIC DIAGRAM OF GMC TYPE 451-1

SECTION V - TABLE OF REPLACEABLE PARTS

CIRCUIT REF.	DESCRIPTION	TOTAL NO. USED	MFRS* CODE	GMC DWG. NO.
C1	Capacitor: fixed, paper dielectric, 0.1 m f, ±10%, 400 vdcw	5	A	
C2	Capacitor: fixed, mica 470 mm f, ±10%, 500 vdcw	1	B	
C3	Capacitor: fixed, silver mica, 1800 mm f, ±5%, 500 vdcw	1	B	
C4	Not used.			
C5	Same as C1			
C6	Same as C1			
C7	Capacitor: fixed, paper dielectric, .27 m f, ±10%, 200 vdcw	1	A	
C8	Capacitor: fixed, mica, 300 mm f, ±10%, 500 vdcw	1	B	
C9	Same as C1			
C10	Capacitor: fixed, mica, 200 mm f, ±10%, 5w vdcw	1	A	
C11	Same as C1			
C12, 13	Capacitor: fixed, paper dielectric, 0.027 m f, ±10%, 200 vdcw	2	A	
C14	Capacitor: fixed, mica, 150 mm f, ±10%, 500 vdcw	1	B	
C15	Capacitor: fixed, paper dielectric, 0.01 m f, ±10%, 400 vdcw	2	A	
C16	Capacitor: fixed, paper dielectric, 0.22 m f, ±10%, 400 vdcw	2	A	
C17	Not used			
C18	Same as C16			
C19A, B, C	Capacitor: fixed, electrolytic, 3 section: 10 m f/sect., 450 vdcw	1	A	

*See "List of Manufacturers Code Letters".

TABLE OF REPLACEABLE PARTS

CIRCUIT REF.	DESCRIPTION	TOTAL NO. USED	MFRS* CODE	GMC DWG. NO.
C20	Same as C15			
C21	Capacitor: fixed, paper dielectric, .47 m f, ±10%, 200 vdcw	1	A	
C22	Capacitor, fixed, ceramic disc, 500pf GMV, 1000V	1	A	
CR1, 2, 3, 4	Rectifier, crystal: germanium diode Type 1N34A	4	C	
F1	Fuse, cartridge: 1 amp, slow blow	1	S	
I1	Lamp, miniature bayonet, #51	1	D	
J1	Connector: type BNC, UG-1094/U	1	E	
L1	Coil, RF: 125 MH	1	GMC	1039
L2	Choke, R.F: 125 MH	1	GMC	1040
M1	Meter,	1	GMC	1038
P1	Cable, power:	1	GMC	2117B
R1	Resistor: fixed, composition, 2700 ohms, ±10%, 1/2 W	1	G	
R2	Resistor: fixed, film 104 ohms, ±0.25%, 1/4W	1	L	
R3	Resistor: fixed, film 200 ohms, ±0.25%, 1/4W	2	L	
R4	Same as R3			
R5	Resistor: fixed, film 521 ohms, ±0.25%, 1/4W	1	L	
R6	Resistor: fixed, film 500 ohms, ±0.25%, 1/4W	1	L	
R7	Resistor: fixed deposited carbon 243 ohms, ± 1%, 1/2W	1	E	
R8	Resistor: variable, wirewound, 100 ohms, 2W	2	K	

*See "List of Manufacturers Code Letters".

TABLE OF REPLACEABLE PARTS

CIRCUIT REF.	DESCRIPTION	TOTAL NO. USED	MFRS* CODE	GMC DWG. NO.
R9	Resistor: fixed, film 476 ohms, ±0.25%, 1/4 W	1	H	
R10	Resistor: fixed, composition, 68,000 ohms, ±10%, 1/2W	3	G	
R11	Resistor: fixed, composition, 560,000 ohms, ±10%, 1/2W	1	G	
R12	Resistor: fixed, composition, 330,000 ohms, ±10%, 1/2W	3	G	
R13	Resistor: fixed, composition, 1500 ohms, ±10%, 1/2W	1	G	
R14	Resistor: fixed, composition, 56,000 ohms, ±10%, 1/2W	1	G	
R15	Resistor: fixed, composition, 100,000 ohms, ±10%, 1/2W	2	G	
R16	Resistor: fixed, composition, 33,000 ohms, ±10% 1 W	1	G	
R17	Resistor: fixed, composition, 4700 ohms, ±10%, 1/2W	1	G	
R18	Resistor: fixed, composition, 560 ohms, ±10%, 1/2W	1	G	
R19	Resistor: fixed, composition, 22,000 ohms, ±10%, 1 W	1	G	
R20	Resistor: fixed, composition, 47,000 ohms, ±10%, 1 W	1	G	
R21	Resistor: fixed, composition, 1 megohm, ±10%, 1/2 W	1	G	
R22	Resistor: fixed, composition, 390 ohms, ±10%, 1/2 W	1	G	
R23	Resistor: fixed, wirewound, 7500 ohms, ±10%, 10 W	1	I	
R24	Resistor: fixed, composition, 10,000 ohms, ±10%, 1 W	1	G	

*See "List of Manufacturers Code Letters".

TABLE OF REPLACEABLE PARTS

CIRCUIT REF.	DESCRIPTION	TOTAL NO. USED	MFRS* CODE	GMC DWG. NO.
R25	Resistor: fixed, composition, 47 ohms, ±10%, 1/2 W	1	G	
R26	Resistor: fixed, composition, 100 ohms, ±5%, 1/2 W	2	G	
R27	Resistor: fixed, composition, 270 ohms, ±5%, 1/2 W	2	G	
R28	Same as R26			
R29	Resistor: fixed, wirewound, 13.5K ohms, ±1%, 10 W	1	J	
R30	Resistor: variable, wirewound, linear taper, 500 ohms, 2 W	2	K	
R30A	Same as R30			
R31	Resistor: fixed, composition, 430 ohms, ±5%, 1/2 W	1	G	
R32	Same as R27			
R33	Resistor: fixed, composition, 240 ohms, ±5%, 1/2 W	1	G	
R34	Resistor: fixed, composition, 200 ohms, ±5%, 1/2 W	1	G	
R35	Resistor: fixed, composition, 160 ohms, ±5%, 1/2 W	2	G	
R36	Resistor: fixed, composition, 130 ohms, ±5%, 1/2 W	1	G	
R37	Same as R35			
R38	Resistor: fixed, composition, 110 ohms, ±5%, 1/2 W	1	G	
R39	Resistor: fixed, composition, 750 ohms, ±5%, 1/2 W	1	G	
R40	Resistor: fixed, composition, 3300 ohms, ±5%, 1/2 W	1	G	

*See "List of Manufacturers Code Letters".

TABLE OF REPLACEABLE PARTS

CIRCUIT REF.	DESCRIPTION	TOTAL NO. USED	MFRS* CODE	GMC DWG. NO.
R41	Resistor: fixed, composition, 2200 ohms, ±5%, 1/2 W	1	G	
R42	Resistor: fixed, composition, 1800 ohms, ±5%, 1/2 W	1	G	
R43	Resistor: fixed, composition, 1500 ohms, ±5%, 1/2 W	1	G	
R44	Resistor: fixed, composition, 1100 ohms, ±5%, 1/2 W	1	G	
R45	Resistor: fixed, composition, 820 ohms, ±5%, 1/2 W	2	G	
R46	Same as R45			
R47	Resistor: fixed, composition, 910 ohms, ±5%, 1/2 W	1	G	
R48	Resistor: fixed, composition, 1000 ohms, ±5%, 1/2 W	1	G	
R49	Resistor: fixed, film 32, 850 ohms, ±0.25%, 1/4 W	1	L	
R50	Resistor: fixed, film 18, 450 ohms, ±0.25%, 1/4 W	1	L	
R51	Resistor: fixed, film 10, 350 ohms, ±0.25%, 1/4 W	1	L	
R52	Resistor: fixed, film 5, 835 ohms, ±0.25%, 1/4 W	1	L	
R53	Resistor: fixed, film 7, 500 ohms, ±0.25%, 1/4 W	1	L	
R54	Resistor: fixed, composition, 2200 ohms, ±10%, 1/2 W	1	G	
R55	Resistor: fixed, composition, 47, 000 ohms, ±10%, 2 W	1	G	
R56	Same as R15			

*See "List of Manufacturers Code Letters".

TABLE OF REPLACEABLE PARTS

CIRCUIT REF.	DESCRIPTION	TOTAL NO. USED	MFRS* CODE	GMC DWG. NO.
R57	Resistor: fixed, wirewound, 68 ohms, ±5%, 1/2 W	1	G	
R58	Same as R8			
R59	Resistor: fixed, wirewound, 150 ohms, ±5%, 1/2 W	1	G	
R60	Resistor: fixed, composition, 470,000 ohms, ±10%, 1/2 W	1	G	
R61	Resistor: fixed, composition, 22,000 ohms, ±10%, 2 W	1	G	
R62	Resistor: fixed, composition, 220 ohms, ±10%, 1/2 W	1	G	
R63	Resistor: variable, wirewound 2000 ohms, ±10%, 2 W	1	K	
R64	Resistor: fixed, deposited carbon, 68,100 ohms, ± 1%, 1/2 W	3	L	
R65	Same as R64			
R66	Resistor: fixed, composition, 1000 ohms, ±10%, 1/2 W	2	G	
R67	Resistor: fixed, composition, 820,000 ohms, ±10%, 1/2 W	1	G	
R68	Same as R12			
R69	Same as R12			
R70	Same as R10			
R71	Same as R10			
R72	Resistor: fixed, composition, 120,000 ohms, ±10%, 1/2 W	1	G	
R73	Resistor: fixed, composition, 150,000 ohms, ±10%, 1/2 W	1	G	
R74	Resistor: fixed, deposited carbon 150,000 ohms, ±1%, 1/2W	1	G	
R75	Resistor: variable, composition, 25,000 ohms, ±20%, 1 W	1	K	

* See "List of Manufacturers Code Letters".

TABLE OF REPLACEABLE PARTS

CIRCUIT REF.	DESCRIPTION	TOTAL NO. USED	MFRS* CODE	GMC DWG. NO.
R76	Same as R64			
R77	Same as R66			
R78	Not used			
R79	Not used			
R80	Resistor: fixed, composition, 100 ohms, ±10%, 2 W	1	G	
R81	Resistor: fixed, wirewound, 10,000 ohms, ±10%, 10 W	1	M	
R82	Resistor: fixed, composition, 33 ohms, ±10%, 2W	1	G	
S1A, B, C, D	Lever Switch 4PDT	2	N	
S2A, B, C, D	Same as S1			
S3A, B, C	Rotary Switch, 2PST	1	O	
S4	Switch, toggle; SPST	1	P	
S5A, B	Rotary Switch, 2P11T	1	O	
T1	Transformer: power	1	GMC	1563
V1	Tube, electron: 6AV6	1	Q	
V2	Tube, electron: 6CB6A	3	Q	
V3	Tube, electron: 6AU5GT	2	R	
V4	Same as V2			
V5	Same as V2			
V6	Tube, electron: 5Y3GT	1	Q	
V7	Same as V3			
V8	Tube, electron: 12AX7	2	R	
V9	Same as V8			
V10	Tube, electron: 5651	1	Q	
RT1	Tube, Ballast, Amperite 8-4	1	T	

* See "List of Manufacturers Code Letters".

LIST OF MANUFACTURERS' CODE LETTERS

Code Letter	Manufacturer	Address
A	Cornell-Dubilier Elec. Co.	So. Plainfield, N. J.
B	Micamold Radio Corp.	Brooklyn, N. Y.
C	Raytheon Mfg. Co.	Waltham, Mass.
D	General Electric Co.	Schenectady, N. Y.
E	Dage	Beech Grove, Ind.
F	Electric-Cord Mfg. Co.	Brooklyn, N. Y.
G	International Resistance Co.	Philadelphia, Pa.
H	Resistance Products Co.	Harrisburg, Pa.
I	Resistors, Inc.	Chicago, Ill.
J	Tech-Ohm Resistor Corp.	L. I. City, N. Y.
K	Chicago Telephone Supply	Elkhart, Ind.
L	Electra Mfg. Co.	Kansas City, Mo.
M	Milwaukee Resistor Co.	Milwaukee, Wis.
N	Centralab	Milwaukee, Wis.
O	Oak Mfg. Co.	Chicago, Ill.
P	Carling Electric, Inc.	W. Hartford, Conn.
Q	Tung-Sol Lamp Works, Inc.	Newark, N. J.
R	Radio Corporation of America	Harrison, N. J.
S	Littelfuse Inc.	Des Plaines, Ill.
T	Amperite Co., Inc.	New York, N. Y.

GUARANTEE

(a) The Contractor guarantees each item against defects in material or workmanship. This guarantee extends for a period of one year, unless otherwise specified, from the date of installation or use, provided that this period shall not exceed two years from the date of delivery.

(b) Upon notice in writing, the Contractor shall promptly repair or replace all defective or damaged items f.o.b. any point designated by the Government within the 48 contiguous States and the District of Columbia, at no expense to the Government. The Contractor may elect to have any replaced item returned to his plant at his expense.

(c) This guarantee shall exclude electron tubes, batteries, natural rubber and material normally consumed in operation unless excepted items fail as a result of improper application by the Contractor, in which case the guarantee shall be equally applicable to these items; provided that the Contractor shall guarantee excepted items to the extent of the guarantee received by the Contractor from his supplier.

(d) If 20 percent or more of the total quantity of any part or component to which the above guarantee applies, but not less than two of any such part or component furnished under the contract, fail in normal service, that fact shall be conclusive evidence that the particular part or component or the item or part design, is unsuitable for the purpose intended. The Contractor, upon notice of this fact, shall replace or correct the design of all quantities of the item or part in a manner satisfactory to the Government, without cost to the Government, unless the use of such part, component or design was specifically required by the Government.

(e) The guarantee period shall exclude any period of time the unit or part fails to perform satisfactorily due to defects.

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